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The Value of Powdery Mildew Resistance in Grapes: Evidence from California

Kate B. Fuller, Julian M. Alston, and Olena S. Sambucci

Powdery mildew-resistant grape varieties currently being developed could yield large benefits to California table, raisin, and wine grape growers—potentially allowing cost savings as high as $48 million per year.

Also in this issue

Powdery mildew (PM) is a fungal disease that can damage many crops. On most plants, PM appears as white, powdery spots on leaves, shoots, flowers or fruit, which if untreated, can spread over large areas of the leaves and stems and cause reduced yields and lower fruit quality. Grape PM, *Erisiphe necator*, is the most prevalent leaf-infecting disease for California grapes. Across the state, it accounts for 74% of grape pesticide use, more than any other grape disease. A range of fungicides can help vineyard managers keep the disease in check in most years, but these are costly and may have negative environmental and human health effects.

For many affected crops, such as melons, squash and peas, PM-resistant varieties have been successfully developed. PM-resistant grape varieties are currently being developed (e.g., the VitisGen project: www.vitisgen.org). We have developed detailed estimates of the differences in costs of production between conventional and PM-resistant varieties of table, raisin and wine grapes, using budgets for hypothetical "representative" individual vineyards.

We use these differences in costs to estimate the potential benefits from PM resistance in grapes over several regions of California. The potential benefits are large but depend critically on the lag until the resistant varieties become available, as well as the subsequent rate of adoption by growers.

Powdery Mildew-Resistant Varieties

Powdery mildew resistance characteristics can be introduced using either conventional or transgenic approaches. Some potential barriers to market acceptance arise when introducing new varieties, developed using either type of technology, especially for wine grapes where the use of traditional *Vitis vinifera* varieties predominates. For table and raisin grapes, these aspects are not as important—many currently popular varieties are relatively new.

Conventional breeding entails crossing *vinifera* varieties, all of which are at least somewhat susceptible to PM, with non-*vinifera* grapes, and then back-crossing to obtain a vine with very high *vinifera* content—perhaps greater than 99%. However, wines made with these hybrid grapes cannot be labeled with the *vinifera* varietal name and could only be sold either without varietal labels, or blended with wine made from a 100% *vinifera* varietal. Even if wines made using grapes from transgenic PM-resistant plants could bear the traditional *vinifera* varietal name, they would probably face significant market resistance because of popular views on genetically modified foods, and would need to go through a substantial regulatory approval process.

Table 1. Powdery Mildew Costs

	Annual PM Cost	Costs Attributed to PM as a Share of Cultural Costs	Cash Costs	Total Costs
	$/acre	*percent*		
Raisin Grapes				
Continuous Tray	222	8.7	4.6	3.4
Tray	222	12.4	6.9	4.5
DOV Open Gable	222	16.3	8.4	4.6
DOV Overhead Trellis	222	16.3	8.3	4.6
Wine Grapes				
Central Coast Chardonnay	369	19.6	12.4	7.7
Table Grapes				
Crimson Seedless	329	8.9	2.4	2.1

In the table grape and raisin markets, traditional varietal names are not as important, but the potential for market acceptance of transgenic varieties remains uncertain. As with conventionally bred PM-resistant vines, transgenic PM-resistant vines might attract a premium from some buyers because they will require much less pesticide.

Measures of Costs and Benefits

The introduction and adoption of PM-resistant grapevines will reduce the use of chemical treatments to mitigate PM impacts. To better understand how the reduction in chemical use would translate into potential cost savings, we constructed budgets for hypothetical "representative" vineyards using updated and revised versions of University of California Cooperative Extension (UCCE) Cost Studies. Our budgets show costs of grape production using conventional and PM-resistant vines for each of the three different types of grapes (table, raisin, and wine).

To validate the budgets we created, we discussed them with experts on each type of grape production system in the regions of interest. This group included extension advisors, pest control advisors, academics, and other researchers. This budget validation process was necessitated by the age of some of the UCCE budgets and our specific interest in PM management costs.

Table 2. Saving in Costs per Acre and per Region from Adopting PM-Resistant Vines

	Elements of Savings in Cultural Costs per Acre: Labor	Fuel, Lube, and Repair	Materials	Total	Total Area, 2011	Maximum Aggregate Benefit
	$/Acre/Year				*Acres*	*$M/Year*
Raisin Grapes						
Continuous Tray	25	17	137	178	88,155	15.7
Tray	25	16	137	177	58,770	10.4
DOV Open Gable	42	30	137	208	24,487	5.1
DOV Overhead Trellis	43	31	137	211	24,487	5.2
Total, All Raisins	29	20	137	186	195,899	36.4
Wine Grapes						
Central Coast Chardonnay	43	47	190	280	26,804	7.5
Table Grapes						
Crimson Seedless	77	51	159	287	12,950	3.7

Grape Types

Grapes produced in California fall into three main categories: wine grapes, table grapes, and raisin grapes. These three categories make up an industry that contributed over $3.8 billion to the value of California's farm production in 2011, and much more in terms of total value. Because resources available for the project were limited, we created budgets only for certain varieties and regions within each grape type, chosen to represent the parts of each industry most affected by PM.

Table Grapes. Of the available table grape varieties, we chose to profile Crimson Seedless grapes—the most widely planted in terms of acreage.

Raisin Grapes. We created budgets for the four predominant types of raisin grape production systems: continuous tray-dried, in which grapes are mechanically harvested and dried on a continuous paper tray between rows; traditional tray-dried, in which bunches of ripe grapes are hand-cut and placed to dry in the sun on rows of individual paper trays; and two types of dried-on-the-vine raisin production systems, in which specially designed trellis systems allow machines to harvest already dried raisins.

Wine Grapes. Because of the great diversity in wine grape growing practices and market characteristics, we opted to focus on the variety that is most affected by PM, chardonnay, which is also the most economically important white wine variety. We also opted to focus on a single region, the Central Coast (crush districts 7 and 8) where PM pressures are most severe.

Vineyard-Level Benefits

In most cases, grape yield is typically not affected by the disease since PM can be preventively controlled with a variety of fungicides. However, the fungicides and the costs of applying them entail significant outlays for growers. The combined cost of fungicide materials and their application amounts to between 8.7% of cultural costs for both continuous tray-dried raisin grapes and crimson seedless table grapes, and 19.6% for Central Coast chardonnay wine grapes. As a share of total cost of grape production, PM treatments account for about 2% for Crimson Seedless table grapes, and 8% for Central Coast chardonnay wine grapes (Table 1).

Table 2 shows differences in specific costs of production—labor, materials, and other costs—between various wine grape production systems using conventional and resistant grapes. The difference in cost between the conventional and the resistant system does not simply equal the current cost of PM treatments. Ending sulfur treatments may result in an erineum mite infestation, so we assume a wettable sulfur treatment would be retained to treat the mites. Additionally, some non-PM treatments are typically applied along with PM treatments, so the labor and fuel, lube and tractor repair costs must be attributed to the non-PM treatments in full and can not be eliminated by adopting the resistant varieties.

Cost savings from growing resistant vines versus conventional vary widely over types of grapes being produced. Total annual cost savings range from $177 per acre in the case of traditional tray-dried raisin production, up to $287 per acre for Crimson Seedless table grapes.

Market-Level Benefits

We now scale up from the per-acre effects for "representative vineyards" to area-wide effects for the regions we have selected: the Central Coast for chardonnay wine grapes, and the San Joaquin Valley for Crimson Seedless table grapes and all types of raisin grapes. Table 2 presents regional acreage and the total cost savings, by production system, if all growers in the region were to adopt a new, resistant variety immediately.

The largest total potential impact is in raisin grapes, which would save $36.4 million per year if all growers converted all the acreage—195,899 acres in the San Joaquin Valley in 2011—to PM-resistant varieties immediately. The corresponding annual cost savings for Central Coast chardonnay is $7.5 million (on 26,804 acres—less than one-fifth that of raisins) and for Crimson Seedless it is $3.7 million (a high per-acre cost reduction, of $287 per acre per year applied to a comparatively small total acreage of 12,950 acres in 2011).

However, a scenario in which resistant varieties become available immediately and all growers immediately adopt them is extremely unlikely. In reality, these new varieties will not become available for some time, and if growers do adopt them, they are likely to do so when the vines they currently have in the ground come to the end of their productive lifespans and have to be replaced anyway. Hence, we allow for various lags until vines become available, as well as various adoption rates.

We also assume that once the vines become available, adoption will increase slowly until it reaches its maximum, 20 years later. Additionally, growers typically do not begin to apply PM controls until the third year after planting, so benefits will not be felt until three years after the R&D lag is over and adoption begins.

Table 3 shows benefits from the resistant varieties over an infinite time horizon, for different adoption rates (denoted *A*, percent) and different lags (denoted *L*, years) until the new varieties become available to growers. Raisin grapes are likely to have the shortest lag as those resistant varieties are nearly fully developed; a ten year R&D lag is possible for that category, whereas resistant varieties of wine and table grapes could take significantly longer to be developed and become available to growers.

The range of estimated benefits is substantial. The present value of the benefit from PM-resistant vines for raisins ranges from as low as $15.6 million, if the resistant vines become available in 40 years and are adopted by 20% of growers, up to $189 million if they become available in 10 years and are adopted by 100% of growers. The present value of the total benefits from PM-resistant vines ranges from $3.2 to $38.9 million

Table 3: Total Present Value of Benefits from Adoption of PM-Resistant Varieties

	Maximum Adoption Rate (A)	Lag (L+3, Years)			
		10	20	30	40
	percent	*$ Millions*			
Raisins: All Types					
	20	37.8	28.1	20.9	15.6
	60	113.4	84.4	62.8	46.7
	100	189.0	140.6	104.6	77.9
Wine Grapes: Central Coast Chardonnay					
	20	7.8	5.8	4.3	3.2
	60	23.4	17.4	12.9	9.6
	100	38.9	29.0	21.6	16.0
Table Grapes: Crimson Seedless					
	20	3.9	2.9	2.1	1.6
	60	11.6	8.6	6.4	4.8
	100	19.3	14.4	10.7	7.9

for Central Coast chardonnay wine grapes, and from $1.6 to $19.3 million for Crimson Seedless table grapes.

Environmental Benefits

The availability and adoption of PM-resistant varieties would entail environmental benefits as well. Fuel, lube, and repair costs are a measure of tractor use. Since tractors emit carbon dioxide, fine particulate matter (PM 2.5), and a host of other pollutants, curbing their use has been a topic of increasing conversation in the San Joaquin Valley, where table and raisin grapes are grown, and where air quality has become an issue of concern in recent years.

Table 2 shows differences in fuel, lube, and repair costs that range from $16 per acre for traditional tray-dried raisin grape production to $51 per acre for Crimson Seedless table grapes. The implication is that PM-resistant varieties would allow some reduction in vineyard operations with an attendant decrease in ambient pollution.

The reduction in applications of chemical fungicides may also yield benefits to the environment and human health, although much is unknown about these effects. Sulfur, the most heavily used agricultural chemical in California, may cause respiratory illnesses and other adverse health effects. However, the kinds of respiratory effects induced and what types of exposure cause them are unknown. In soil, bacteria slowly convert sulfur to sulfate, which generally does not cause harm. Other (relatively new) synthetic compounds used for PM treatment and prevention, such as sterol inhibitors and strobilurns, have not been reported as having negative environmental or human health effects.

Because of the large volume and frequency of applications, controlling for PM results in the bulk of the environmental impact from grape production, even though the fungicides used for PM control are less toxic to both humans and the environment than many other pesticides. The reduction of these environmental and human health costs is one of the benefits from growing PM-resistant varieties.

Several measures of pesticide risk are available to examine the environmental impact of PM management. These measures include the Environmental Impact Quotient (EIQ), which combines pesticide hazards to farm workers, consumers and the environment, and the Pesticide Use Risk Evaluation (PURE), which is a California-specific index that quantifies the environmental risk to soil, surface water, ground water, air, and bees. Using either measure, sulfur accounts for a large share of environmental risk. Environmental benefits from eliminating PM-related fungicide applications would accrue primarily to workers (reduced potential health risks), and through reduced harm to bees and soil.

Conclusion

Powdery mildew is a common disease that imposes large economic costs on California grape growers. PM-resistant varieties of grapes could yield large economic benefits to grape producers in California—potentially as high as $48 million per year in the subset of the industry covered by our analysis—across wine, table, and raisin grape-producing sectors. Our estimates of the cost savings attributable to PM-resistant varieties range widely across the different grape production systems, with the greatest potential in the raisin grape industry. Within a system, the benefits are quite sensitive both to the R&D lag until the resistant varieties become available for adoption, and to the maximum adoption rate.

The measures of potential cost savings we present here represent only part of the economic picture for two reasons. First, they count only part of the potential cost savings. We estimate only private cost savings for certain regions, and do not include benefits from reduced pesticide use or benefits for wine grapes other than chardonnay produced in the Central Coast region.

On the other hand, we have implicitly assumed prices of grapes grown using PM-resistant varieties would be the same as prices for grapes from the conventional varieties they would replace. Grapes produced using non-*vinifera* or transgenic vines might well suffer a price discount compared with conventional alternatives, and if the price discount is greater than the cost savings from resistance, then it will not make economic sense for growers to adopt them. Even if it is not prohibitive, any price discount will offset the benefits from cost savings to some extent.

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For additional information, the authors recommend:

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Davis, R.M., W.D. Gubler, and S.T. Koike. 2008. “Powdery Mildew on Vegetables.” www.ipm.ucdavis.edu/PMG/PESTNOTES/pn7406.html.

University of California Cooperative Extension. 2000–2011. Cost and Return Studies. http://coststudies.ucdavis.edu.

How California Farms Measure Up in the 2012 Census of Agriculture: Smaller in Size with Higher Value of Production

Emma C. Knoesen and Rachael E. Goodhue

The 2012 Census of Agriculture was released in early May 2014. Average farm size continues to grow in terms of acreage and market value of production. However, this trend is not universal across crop category or geographic region. For the crop category of Land Used for Vegetables, the average acreage allocation per farm reporting production in this category decreased, while certain counties in California experienced an increase in the average acre allocation.

Conducting an agriculture census has been a longstanding activity of the federal government. The 2012 Census of Agriculture was the twenty-eighth U.S. agriculture census. The first agriculture census was in 1840 and a new one has been conducted every five years since 1920. The aim of the census is to provide detailed information on U.S. farms and ranches and their operators to the public, businesses, the government, and analysts. The census summarizes information at the national, state, and county levels. Some information is not reported publicly in order to maintain confidentiality regarding individual operations.

The Census of Agriculture enables the comparison of California agriculture to U.S. agriculture. The 2012 census indicates that differences between the two, regarding farm size by acreage and market value of agricultural products, were consistent with the differences reported in 2007 and earlier recent censuses. We focus here on comparing these characteristics in 2012.

California had smaller farms on average by acreage, with an average farm size of 328 acres, while the United States had an average of 434 acres. Overall, California had a larger percentage of small farms, while the U.S. had more large farms. As seen in Table 1, which documents the size of farms by acreage in California and the United States, a majority (65%) of California farms in 2012 were under 50 acres. Only 39% of farms in the United States were under 50 acres. At the other end of the spectrum, 15% of United States farms were over 500 acres, compared to 10% in California.

While California farms tended to be smaller in terms of acreage, California has more high-value crops, which generate more revenue per acre. These high-value crops mean that California farms tend to have a higher market value of agricultural products sold. The average market value of production per acre of farmland in California was $1,667, compared to $289 in the United States as a whole in 2012.

Table 2 (on page 6) reports the size of farms in 2012 by their market value of production before taxes or production costs. California had a larger percentage of farms with a large market value of production. Over a quarter, of California farms had a market value of production over $100,000, in comparison to 19% nationally. On average, farms in California had a market value of production a little under three times the national average: $547,510 for California and $187,097 for the United States.

Evolution of California Agriculture

The census also allows for the evaluation of the development of California agriculture over time because it is conducted every five years. Here, we compare the market value of agricultural products sold and the acreage of farms in 2007 and in 2012. Census data show that over this time period, the average market value of production of California farms increased by 31%. This increase was due to both a reduction in the total number of farms in California and an increase in the number of farms with a large market value of production.

Table 1: Farm Size by Acres: California and the United States, 2012

	California		United States	
Acres	Number of Farms	Percentage of Farms	Number of Farms	Percentage of Farms
1 to 9 acres	24,637	32	223,634	11
10 to 49 acres	25,811	33	589,549	28
50 to 179 acres	13,056	17	634,047	30
180 to 499 acres	6,649	9	346,038	16
500 to 999 acres	3,230	4	142,555	7
1,000 to 1,999 acres	2,040	3	91,273	4
2,000 acres or more	2,434	3	82,207	4
Average Acreage/Farm	328		434	

Source: 2012 Census of Agriculture

Table 2. Farm Size by Market Value of Agricultural Products Sold: CA and the U.S., 2012

	California		United States	
Market Value	**Number of Farms**	**Percentage of Farms**	**Number of Farms**	**Percentage of Farms**
Less than $2,500	19,347	25	665,311	32
$2,500 to $4,999	5,904	8	231,388	11
$5,000 to $9,999	7,846	10	248,616	12
$10,000 to $24,999	10,265	13	271,511	13
$25,000 to $49,999	7,150	9	161,939	8
$50,000 to $99,999	6,698	9	133,988	6
$100,000 to $499,999	11,083	14	237,328	11
$500,000 or more	9,564	12	159,222	8
Average Market Value/Farm	$547,510		$187,097	

Source: 2012 Census of Agriculture

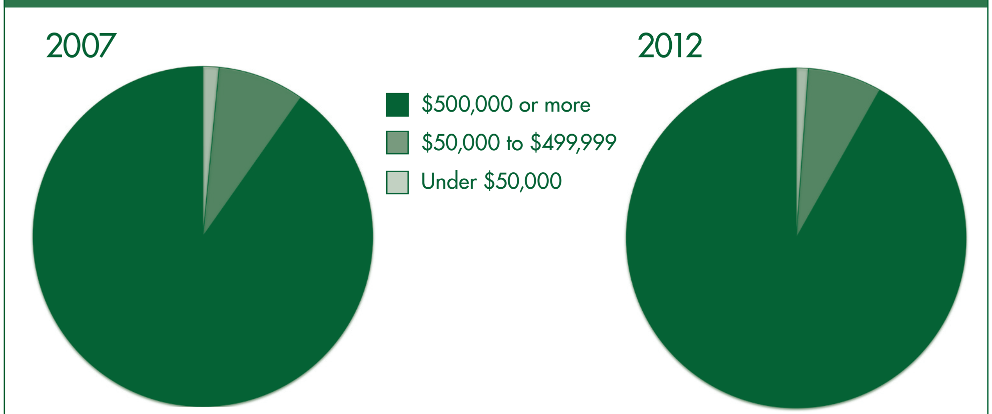
The total number of California farms fell from 81,033 in 2007 to 77,857 in 2012. At the same time, the number of farms in the largest range of market value of production, $500,000 or more, increased from 8,649 to 9,564. These trends were also apparent nationally.

Comparing the pie charts in Figure 1, California farms with a large market value of production increased their share of the total market value of production of all California farms. Even though they are only about one-eighth of California farms, those with a market value of production over $500,000 produced a substantial majority of the total market value of production of California farms—92% in 2012, a slight increase from 90% in 2007. California farms' market value, as well as the percentage of total revenue produced by these higher market value farms, increased.

As mentioned earlier, California has a significant number of small farms by acreage and also in market value of production. The majority of farms in both years had a market value of production under $50,000—57% in 2012 and 59% in 2007 as seen in Figure 2. There is considerable heterogeneity within this category.

Of the farms with a market value of production under $50,000, 38% were under $2,500 in 2012, compared to 42% in 2007. In both 2007 and 2012, 14% of the farms with a market value of production under $50,000 had a market value of production between $25,000 and $49,999. While there are many small farms, they do not produce a large part of the total market value of production of all California farms. Within the category of market value of production under $50,000, these farms produced 1.5% of the total market value of all California farms in 2007 and 1.1% in 2012.

Figure 1. Share of Total California Agricultural Production by Farm Size Category, 2007 and 2012



Variation Across Crop Category

The census reports the number of farms and acres by crop category. This information allows analysis of the land allocated to and the number of farms producing a specific crop. Here, we report changes in farms with orchards and farms with vegetable and melon production. The definitions used in the census are important for this analysis. For a given crop category, the number of farms is all farms that reported producing that crop, and the acres are the cumulative acres reported for that category. If a farm harvested two or more crops in different categories from the same land, the acres and the farm itself were counted in each crop category. However, if two or more crops in the category Land Used for Vegetables (LUV), which includes all vegetables and melons, were harvested from the same acreage, then the census only counts the acres once. Land in Orchards (LO) includes all acreage with fruit trees, citrus or other groves, vineyards, and nut trees of nonbearing and bearing age, regardless of whether or not it was harvested.

Over the five years between 2007 and 2012, LUV and LO experienced opposite changes in farm size and number. As exhibited in Figure 3, the number of farms with LUV increased by 57%, while acres allocated for vegetables or melons increased only 2%; in 2012, the farms tended to allocate less acres to this category than in 2007. The average acres allocated as LUV per farm decreased from 251 acres in 2007 to 163 acres in 2012.

In contrast, the acres allocated as LO per farm grew in size. The number of farms with LO decreased by 4% while acres in LO increased by 10% from 2007 to 2012. This change resulted in an increase in the average acres of LO per farm from 72 acres in 2007 to 82 acres in 2012, or an increase of 13%.

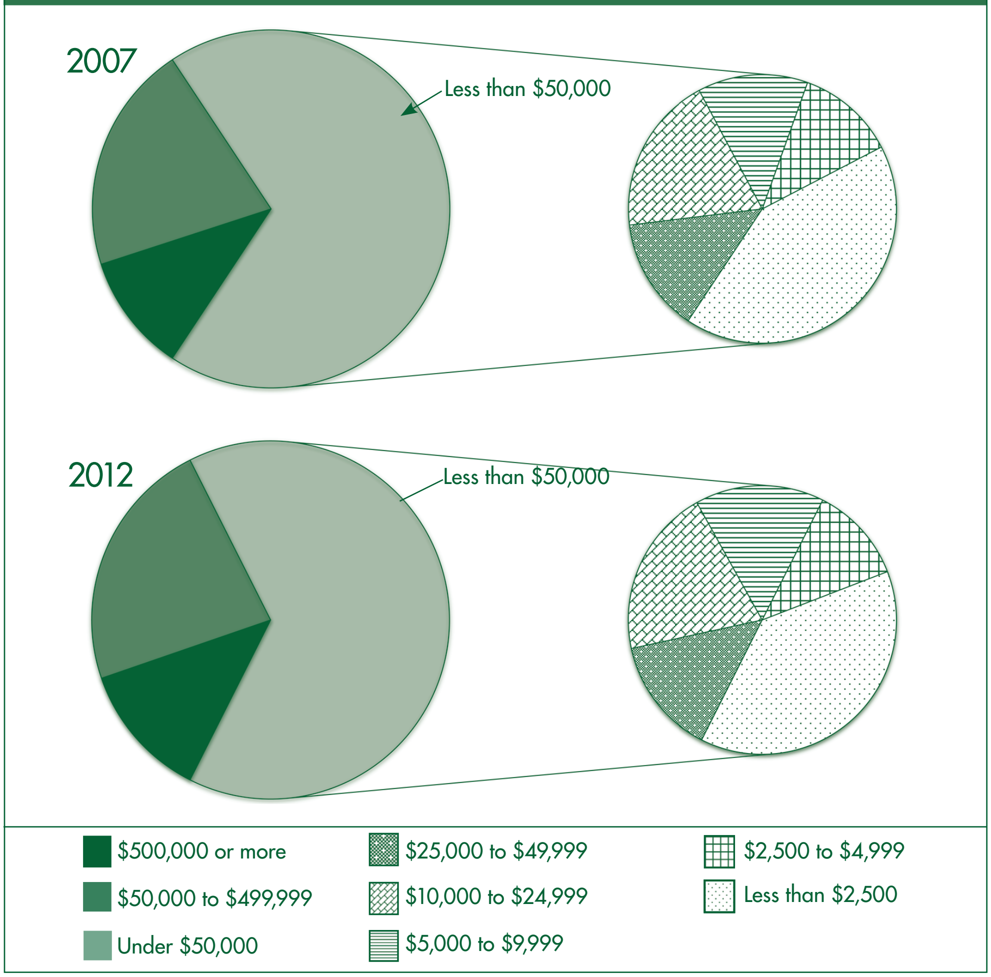
County by County Variation

The census provides data on a county level as well. These data enable the comparison of trends on the county, state, and national level. Here, we link the statewide trend of smaller acreage allocation per farm in LUV to developments in major vegetable-producing counties. Of the top ten counties in LUV by acreage, only six experienced a decrease in the average allocation of acres to LUV: Fresno, Kern, San Joaquin, Merced, Yolo, and Santa Barbara.

Table 3 (on page 8) illustrates that four of the top ten vegetable-producing counties in 2012 realized an increase in average vegetable acreage per farm: Monterey, Imperial, Riverside, and Ventura. In Monterey County, the number of farms with LUV increased from 202 in 2007 to 210 in 2012, while the acres allocated as LUV increased from 163,237 acres to 189, 644 in that same time. As the county with the largest acreage of LUV in 2012 and the second largest in 2007, Monterey realized a 12% increase in the acre allocation per farm.

A similar trend was seen in Imperial County in which the number of farms with LUV increased from 86 to 105 and the acres allocated increased from 68,970 acres to 105,979 acres from 2007 to 2012. In 2012 Farms with LUV in Imperial County allocated 1,009 acres on average per farm to vegetables or melons, the largest across all California counties. Imperial County had the third most acres in LUV in 2012 and the fourth most in 2007. Imperial County's average allocation per farm increased 26% from 2007 to 2012.

Figure 2. Share of Total California Farms by Level of Sales, 2007 and 2012



Conclusion

The Census of Agriculture is an important tool for analysts, the government, businesses, and the public. It enables the analysis of production, agriculture's evolution over time, and the comparison of agriculture in different geographic regions. The 2012 Census of Agriculture indicates that California agriculture remains distinct

Figure 3. California Farms with Land Used for Vegetables and Land in Orchards

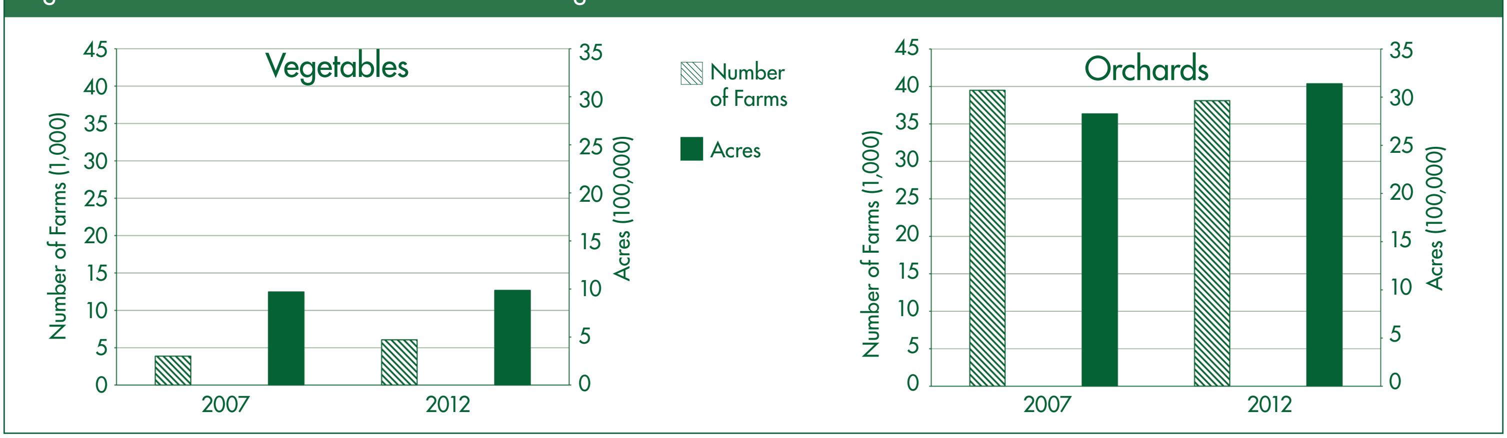


Table 3. Land Used for Vegetables in the Top Ten Counties by Acreage in California, 2012 and 2007

County	Number of Farms with Land Used for Vegetables	Land Used for Vegetables (Acres)	Share of CA Land Used for Vegetables	Average Land Used for Vegetables per Farm
2012				
Monterey	210	189,644	19%	903
Fresno	564	166,810	17%	296
Imperial	105	105,979	11%	1009
Kern	167	84,962	9%	509
San Joaquin	193	52,651	5%	273
Merced	223	51,119	5%	229
Yolo	114	43,449	4%	381
Santa Barbara	222	40,594	4%	183
Riverside	155	30,529	3%	197
Ventura	106	25,027	3%	236
All other	3,996	194,971	20%	49
California	6,055	985,735		163
2007				
Fresno	559	186,565	19%	334
Monterey	202	163,237	17%	808
Kern	138	77,362	8%	561
Imperial	86	68,970	7%	802
San Joaquin	181	66,652	7%	368
Merced	176	58,671	6%	333
Yolo	96	48,034	5%	500
Santa Barbara	145	42,436	4%	293
Kings	53	28,982	3%	547
Ventura	118	24,458	3%	207
All Other	2,114	203,646	21%	96
California	3,868	969,013		251

Source: 2012 Census of Agriculture

from U.S. agriculture as a whole, although in both cases farms continue to grow larger in both acreage and market value of production. California tended to be smaller on average by acres than the rest of the country, yet continued to have farms with higher market value of production from high-value crops. Though the total number of farms in California decreased from 2007 to 2012, the total market value of production of California farms increased by just over one-quarter.

However, the trend towards larger farms was not universal across all farm types—at least not when measured in acres. LO followed the national as well as state trend with the average acreage allocated by each farm to orchard production growing by 13%. Land Used for Vegetable followed a different trend, with a smaller acre allocation per farm producing vegetables and melons in 2012 than in 2007. The number of acres per farm with LUV decreased just over 35%.

However, this trend was not consistent in every county in California. Some counties, such as Imperial and Monterey, with some of the largest total acreage of LUV, experienced an increase in their average acre allocation per farm. Other counties, such as Fresno, Santa Barbara and Yolo, experienced a decrease in their average acre allocation to LUV per farm, similar to the state trend. The 2012 Census of Agriculture confirms that the agricultural landscape of California is diverse and general trends do not hold for all commodities.

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For additional information, the authors recommend:

2012 Census of Agriculture. www.agcensus.usda.org/Publications/2012/. The site includes expanded descriptions of methodology and information on other states as well as previous censuses.

Assessing Environmental Impacts of Genetically Modified Seeds in Brazilian Agriculture

Renato Seixas and José Maria Silveira

Using a farm-level dataset on genetically modified (GM) seed adoption and pesticide application in Brazil, we find that Insect Resistant (IR) cotton reduces the environmental impact of insecticides but Herbicide Tolerant (HT) soybeans increase the environmental impact of herbicides due to weak substitution among herbicides of different toxicity levels.

Genetically modified (GM) seeds have been considered one of the major technological innovations for agricultural systems and have been promoted as an effective tool for controlling agricultural pests and expanding food supply. Their relevance can also be measured by the wide span of controversial issues that have been raised by the related literature, such as: intellectual property rights over organisms, productivity effects, economic returns, consumer safety, welfare and income distribution, and environmental effects.

On the environmental front, benefits from adoption of GM seeds have been argued based on findings about pesticide use and agricultural practices. Insect Resistant (IR) cotton has been found to reduce the use of insecticides and therefore produce environmental, health and safety gains. Herbicide Tolerant (HT) soybeans have been found to change the mix of herbicides applied towards less toxic chemicals and to allow the use of no-till cultivation techniques, leading researchers to conclude that they also produce environmental benefits.

This article addresses the environmental impacts, associated with pesticides use, resulting from adoption of GM seeds in Brazil. We innovate relative to previous works on this topic by employing a broader measure of environmental impact that takes into account toxicity levels and risk of exposure in evaluating the effects of pesticides for different dimensions of agricultural systems. Hence, we are able to uncover environmental impacts that have been hidden by the qualitative nature of the change in the mix of pesticides used.

GM Seeds and Pesticides Use

Since the mid 1990s, when first-generation GM seeds were commercially introduced, adoption by farmers has grown steadily in industrialized and developing countries as they provide an alternative and more convenient way of controlling pest damage. By 2008, 13.3 million farmers dedicated 8% of total cropland (12.5 million ha) to the cultivation of GM seeds. The leading countries in terms of share of cultivated area in 2009 were the United States (50%), Argentina (17%), Brazil (13%), India (6%), Canada (6%), and China (3%).

In Brazil, the most recent nationwide survey on agricultural biotechnology adoption indicates that GM seeds account for 91.8% (27.4 million ha) of soybean cultivated area, 81.6% (12.4 million ha) of maize, and 65% (0.71 million ha) of cotton-cultivated area. The main traits that have been introduced in first-generation GM seeds correspond to HT and IR technologies. The focus of this article relies on HT soybeans and IR cotton.

IR seeds are engineered to produce a natural toxin found in the soil bacterium *Bacillus thuringiensis* (Bt), which is lethal to a number of bollworm pests but not to mammals. In other words, the IR trait works as a substitute for insecticides that control bollworm infestations. IR crops have been considered technically and economically efficient for producers, allowing savings in labor and machinery used in insecticide applications. This potential is higher in regions with high infestations—typically, less-developed countries in tropical weather regions with high rates of insecticide use. Besides, it has also been considered a more efficient tool for managing risk of pest attack, allowing reduced expenditure on crop insurance. The result in terms of the outcome of interest is straightforward: less insecticide usage reduces associated environmental impact.

Weeds are strong competitors with soybean plants for nutrients, water, and sunlight. Weed control techniques have evolved from traditional mechanical methods to herbicide applications, which were introduced in the 1960's. Soybean seeds engineered with HT traits were introduced in 1996 under the commercial name *Roundup Ready®*. They are the result of the transfer of part of the genetic code of a soil bacterium, *Agrobacterium tumefaciens*, which allows the plant to metabolize the herbicide glyphosate (Roundup). In 1998 soybean varieties tolerant to the herbicide glufosinate were introduced under the commercial name *Liberty Link®*. These herbicides are considered less toxic than others and

Table 1. Estimates of Impact of IR Cotton and HT Soybeans on Quantity of Pesticides (Insecticides and Herbicides) and Environmental Impact (EIQ)				
	Insecticies (Kg/ha)	Insecticides + (EIQ)	Herbicides (Kg/ha)	Herbicides+ (EIQ)
IR Cotton	-0.242^{***}	-0.234^{***}	-	-
	[0.037]	[0.035]	-	-
HT Soybean	-	-	0.442^{***}	0.356^{***}
	-	-	[0.056]	[0.049]
N	120	120	170	170
r^2	0.913	0.918	0.755	0.790

*+ Robust standard errors. * p < 0.05, ** p < 0.01, *** p < 0.001*

Coefficients multiplied by 100 indicate approximate percentage variation.

target a large variety of broad-leaf and grass weeds species, but cause severe damage to conventional crops when applied after germination.

By making the soybean plant less susceptible to damage caused by those chemicals, the HT trait induces farmers to apply more of them. The resulting environmental impact is ambiguous though: farmers are induced to apply more of less toxic herbicides, but the net effect depends on how much they substitute for more toxic ones. Hence, increasing the share of less toxic herbicides in the quantity of pesticides applied is not enough to guarantee a reduction in environmental impacts associated with these chemicals.

This discussion suggests that measuring environmental impacts associated with pesticide use is not straightforward. For HT traits, specifically, the net effect on environmental impact is an open issue. Economists who studied it have focused on the change in the mix of herbicides to conclude that there are environmental gains allowed by the use of HT traits. Nevertheless, we argue that weak substitution might undermine this conclusion, as we show in the analysis that follows on the next section.

Empirical Strategy

In the empirical analysis, we use a unique farm-level dataset originated from a survey conducted by a private firm in Brazil. The survey collected data on production, revenue, costs, biotechnology adoption, and pesticides used. Information on pesticide use was collected for harvest seasons 2009–2011 and covers 839 farms.

The dataset is disaggregated by fields, within a farm, cultivated with conventional or GM seeds. In other words, for each farm, we have potentially multiple observations related to fields cultivated with conventional or GM seeds. This setup allows us to use *within-farm* variation for farmers who plant both conventional and GM seeds to identify the effect of adoption on the environmental impact of pesticides. This empirical strategy holds constant all farm-level characteristics that might simultaneously affect the choices of pesticide use and biotechnology adoption, such as management skills, input/output prices, location, weather shocks, etc.

The farms surveyed represent large operations with potentially large environmental impacts associated with the scale of production and pesticide use. For cotton growers, the average total planted area is 2,521 ha, ranging from 60 ha to 28,374 ha. For soybean growers, the average total planted area is 1,240 ha, ranging from 8 ha to 13,500 ha. In terms of experience, farmers report an average of 22.4 and 29.4 years for cotton and soybeans, respectively.

We measure the environment impact as two outcome variables: quantity (Kg/ha) of active ingredients of chemicals, and the Environmental Impact Quotient (EIQ) index. This measure of environmental impact of pesticides was designed to capture risks associated with both toxicity levels and exposure to chemical pesticides on three components of agricultural systems: farmworker, consumer, and ecological. Hence, the EIQ index provides a more complete picture than just the composition of the mix of pesticides used, allowing for an adequate weighting of pesticides with different toxicity levels.

The use of the EIQ index represents a big advancement over previous studies, which relied on an increased share of less toxic chemicals of the total quantity (Kg/ha) of herbicides applied in HT soybeans fields, since this measure cannot capture environmental effects due to substitution between herbicides. If the increase in the use of less toxic herbicides is not accompanied by a sufficient decrease in more toxic ones, the new mix of herbicides induced by HT seeds can be more harmful than the one

Table 2. Estimates of Effects of HT Trait on Quantity of Herbicides per Toxicity Level				
	Herbicides 1 (Kg/ha)	Herbicides 2 (Kg/ha)	Herbicides 3 (Kg/ha)	Herbicides 4 (Kg/ha)
HT Trait	-0.084^{***}	-0.005	0.635^{***}	0.438^{***}
	[0.021]	[0.054]	[0.098]	[0.090]
N	168	168	168	168
r2	0.887	0.777	0.855	0.845

*Robust standard errors in brackets. * p < 0.05, ** p < 0.01, *** p < 0.001*

Note: toxicity levels 1-4 in decreasing order (from more to less toxic). Herbicides based on glyphosate are considered of lower toxicity level.

induced by conventional seeds. The EIQ index calculated for field operations allows us to adequately weight pesticides of different toxicity levels and gets around the difficulties of looking only at the quantity mix of pesticides used.

Findings

Our findings are summarized in Table 1. The dependent variables are logs of quantity (Kg/ha) of pesticides and of the EIQ index. The independent variable of interest is a dummy indicator for adoption of IR cotton or HT soybeans. Results show that adoption of IR cotton reduces the amount of active ingredients of insecticides used by 24.2%, and the environmental impact index by 23.4%, when compared with fields cultivated with conventional seeds. In absolute terms, this is equivalent to a reduction of approximately 0.956 Kg/ha of active ingredients.

For HT soybeans, although farmers use more of less toxic herbicides, we estimate that the net environmental impact is higher than for conventional seeds. We find that adoption of HT seeds causes an increase of 44.2% of active ingredients (Kg/ha), and a corresponding 35.6% increase in the EIQ index when compared with fields cultivated with conventional seeds. In absolute terms, this corresponds to an increase of 0.996 Kg/ha of active ingredients.

Table 2 sheds light on the mechanism that drives the results for HT soybeans. It shows estimates of the impact of HT seeds on the quantity of active ingredients (Kg/ha) of herbicides of different toxicity levels. The reductions in higher toxicity herbicides (columns 1 and 2) are very modest when compared to the increases in lower toxicity ones (columns 3 and 4). In absolute terms, we estimate that the increase in the later is *twelvefold* the decrease in the former. This result indicates that weak substitution among herbicides of different toxicity levels causes a net increase in the environmental impact associated with herbicides.

Our results confirm the environmental gains from IR cotton but suggest that the prior findings on the environmental effects of HT soybeans have been misled by relying solely on the change in the mix of herbicides used.

Conclusions

In this article, we analyze the environmental effects related to the use of pesticides arising from adoption of IR cotton and HT soybean seeds. Using *within-farm* variation across fields treated with conventional and GM seeds, we find that IR cotton reduces the amount of insecticides applied to cotton crops. HT soybeans, on the other hand, leads to more use of herbicides.

Analysis using the EIQ index shows that IR cotton reduces the environmental impact by about 23% in the treated fields compared to fields cultivated with conventional seeds. This is consistent with the previous result on Kg/ha of insecticides, and confirms the environmental impact-saving nature of the IR technology. The resulting environmental effects for HT soybeans, on the other hand, are found to be negative. The estimates imply that the impact of herbicides is increased by 35.6% compared to fields cultivated with conventional seeds.

Looking at quantities of herbicides of different toxicity levels, we see increases in the use of lower toxicity herbicides and very small reductions in higher toxicity ones. This finding indicates very weak substitution among herbicides, which explains the higher environmental impact associated with these chemicals caused by adoption of HT soybeans.

We believe this to be an important result for three reasons. First, it contributes to uncover environmental effects that have been hidden by the qualitative nature of the mix of herbicides induced by the HT trait. Second, environmental policy makers designing policies for biotechnology adoption might consider this new evidence to differentiate among GM traits that produce positive or negative externalities. Finally, as the composition of the EIQ index suggests, the environmental impact of pesticides can have multiple dimensions that might involve farmworker health and safety, consumer safety, and ecological impacts. Hence, the results on HT soybeans suggest additional avenues of work that should be taken to evaluate each of these possible channels since they can also affect other important outcomes.

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Celeres. 2014. Biotech Newsletter. Celeres, Uberlândia (MG). Retrieved from www.celeres.com.br.

Kovach, J., C. Petzoldt, J. Degnil, and J. Tette. 1992. "A Method to Measure the Environmental Impact of Pesticides." Ithaca, NY: New York State Agricultural Experiment Station, a division of the New York State College of Agriculture and Life Sciences, Cornell University.

Qaim, M. 2009. "The Economics of Genetically Modified Crops." *Annual Review of Resource Economics*, 1, 665 - 694. www.annualreviews.org/doi/abs/10.1146/annurev.resource.050708.144203.

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